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INVESTIGATION OF FRAGMENTS FROM SPACE VEHICLES

Gilbert Larsson

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ABSTRACT. In the present report an account is presented of an investigation of two found objects of foreign origin. The purpose was to determine their nature, origin and use, and to try to develop a certain routine for investigations of this kind. The result of the investigation shows that one object has been identified with a high degree of probability as a component of space vehicle 1965-26A. The second object might be derived from one of six indicated space vehicles from 1964. In both cases the origin is American.

In this report the result is presented of an investigation that has been made of two found objects of foreign origin. One was found in the Harjedal mountains, in the Vemdalen region, the other a couple of miles from Borås. /4*

The purpose of the investigation was to determine their nature and use. Because it was clear at an early stage that the material was a qualified high metal, a titanium alloy, the material analysis has been relatively extensive. Alloys of this type are used only to a limited extent in this country.

The following institutions have cooperated:
1. FOA M, structure and microprobe analysis.
2. FOA 4, Spectroscopic analysis.
3. Statens Provningsanstalt, (State Testing Institute), chemical analysis.
4. Statens Kriminaltekniska Anstalt (State Criminological Institute) visual examination under ultraviolet and infrared light.

Appendix 3, "Memo concerning investigation of foreign material" and section 3 of this report, "Possible origin" were written by the Chief of Division 160, laboratory director A. Hjertstrana. Appendix 9, "Metallographic structure investigation of a welded spherical container of light metal sheet" was written by N-E Karlsson, 1st engineer, FOA M.

The two objects are spherical and are in the following called "The Vemdal Sphere" and "The Borås Sphere" respectively.

1. THE VEMDAL SPHERE

The object was found during moose hunting 8 September 1964, (app. 1). A preliminary examination was carried out at F4, (app. 2), whereupon the find

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*Numbers in the margin indicate pagination in the foreign text.

was forwarded to FOA. After examination of the find and circumstances connected therewith it was decided on 19 Novermber 1964 that a more intensive examination should be carried out, (app.3).

An inspection of the site of the find was regarded as being of primary interest, but could not be carried out due to snow. Due to the pressure of work the visit to Vemdalen did not become a reality before September 1965. /5

As it was clear already from the beginning that the material was a titanium alloy, data were obtained on types of alloys occurring abroad, at the same time as various analyses were ordered.

11. Site of Find

Ca 1.5 km NW of Vemdalen church village. It has not been possible to locate the point of impact precisely, but it lies between the UTM coordinates VK445-VK455 and VK365-VK375, map sheet 72 ASARNA.

September 27-28 1965 an inspection was made of the find area. Due to haze and misty fog the site of the find, marked by the finder, could not be found again. The terrain is very hilly, broken and difficult to survey. The possibilities for additional finds by systematic search were judged to be very small. Figure 1 gives an idea of the condition of the terrain, Figure 2 is an air photo of the area.

12. Time of Impact

No observations of the landing are known. The sphere was found 8 September and arrived at FOA in the middle of October 1964. In the interior of the sphere there were found some small lingon berry twigs. These had entered through the opening formed by the impact. The twigs were still green, without any incipient wilting. No traces of insects, such as spiderwebs or the like, were present.

This could be interpreted to mean that the impact did not take place during or prior to the preceding frost period, which in that locality lasts until May - June, otherwise the twigs would have been brown. The absence of insects does not necessarily indicate that the sphere had been on the site only a short time. To most insects metal objects are not attractive for habitation. If, on the other hand, the sphere had been long in the place, it can be assumed with some probability that some tracks of insects or small rodents would have been found. The finder, an experienced woodsman, had the general impression that the sphere had landed at the site a relatively short time before being found.

From the circumstances on which the judgment is based the conclusion may be drawn that the impact occurred during the three months period preceding 8 September 1964. /6

13. Appearance

The shape is spherical, with projecting nipples at the poles. These show melting damage. One nipple is threaded, the other is so severely damaged that its appearance cannot be directly reconstructed. It can be assumed with some justification however, that it has been threaded. As it lacks a bore it may have been used as point of attachment for installation. The bond nipple was provided with a thin nut.

The surface of the sphere shows that it had been exposed to heating. The color is mainly brown in various shades. Traces of molten metal were visible near the nipples.

The sphere is made of two hemispherical shells, with a nipple at each pole and joined together by a machine made weld along the equator. Reference is made to Figure 4 concerning this method of manufacture.

At the impact, which probably was against a rock, a burst occurred. The appearance of the sphere is seen from Figures 3 and 4.

14. Dimensions

Because the sphere was deformed on impact no claim of accuracy can be made for the measurement. The dimensions given are average values for three measurements in different directions.

Weight	5.28 kg
Outside diameter	371.74 mm
Inside diameter	366.50 mm
Thickness of material (varies)	2.62 mm
Volume (calculated)	25.76 dm^3 = 1572 cu. in. = 6.8 US gallons
Hardness	321-329 HB, 37-40 RC

The locknut:

Wrench width	38.32 mm, 1 1/2" - 1 33/64"
Thickness	7.28 mm, 9/32 - 19/64"
Thread	SAE 1" - 14

See also dimension sketch, Figure 5.

15. Material /7

The investigation according to appendix 3 showed that the only possible material was a titanium alloy. To get a rough estimate of the composition a spectroscopic analysis was performed. It was judged probable that the material was one of the two alloys most common in the US, 5 Al + 2.5 Sn or 6 Al + 4V respectively, wherefore the analysis was carried out with these alloying elements in mind. Results as in appendix 5.

The spectroscopic analysis was followed by a chemical titanium determination (app.6). The result of this gave a too high titanium value in relation to the other elements, namely 93.4%. The reason for this is probably that the analysis method used causes the vanadium to be "masked" by the amount of titanium.

A reviewed spectroscophic analysis gave a somewhat more comprehensive result, (app.7).

A chemical Al determination produced as result the Al content together with a statement about the probable type of alloy, (app.8).

To determine more precisely the type of material a structural analysis was performed, supplemented by a microprobe analysis. These examinations are reported on in appendix 9.

As appears from the analysis record there should not be any doubt whatever that the material corresponds to the American ASTM B 265-58T. According to available data the material occurs among others under the following designations:

Crucible Steel Co	C-120AV
Harvey Aluminum	HA-6510
Reactive Metal Products	MST-6Al-4V
Republic Steel Co	RS-120A
Titanium Metals Corp	Ti-6Al-4V
AMS	4928A
Mil. des.	OS-10737

Material data (typical)
Melt pt. 1650 ± 25°C, Sp.W. 4.43, Str.gr 82kp/mm^2, Hardness 300 HB

The alloy also occurs in a variant with low impurity contents.

16. Other /8

The surface of the sphere has been inspected visually for traces of text or other markings, but without result. The State Criminological Institute has in addition done the same partly in long-wave, partly in short-wave ultraviolet illumination and by infrared photography, all with negative results.

17. Conclusions

The object is certainly a spherical pressure vessel. According to appendices under 13, the material corresponds to ASTM B 265-58T. The titanium alloy of the type 6 Al - 4 V is in the US the most used for the manufacturing of pressure vessels for space vehicles. It is true that the USSR also uses similar alloy types, but the dimension and general appearance of the measured thread speaks against its being of Soviet origin.

Material of this type is used both in space vehicles and in airplanes. The probability of the vessel under investigation being derived from an airplane is very small. The nature of the melting damage is such that it could only have arisen under intense heating and high velocity. Even for an airplane at the highest altitude all essential conditions are lacking.

The conclusion is therefore that this Vemdal sphere is from a space vehicle of American origin.

2. THE BORÅS SPHERE

An object of the same type as the Vemdal sphere was found in the Borås region in the beginning of April 1965. It was delivered to FOA 1 the 18th of October the same year after previous examination at F 9, Såtenas (app. 10).

21. Site of Find

It has been possible to locate this exactly because the impact was observed. The place has UTM coordinates UE64062, map sheet 33, BORAS. The area was visited 21 January 1966. The place is, like that in Vemdalen, relatively desolate and mixed with lakes, tarns, bogs and woods. The possibility for further finds was judged small. Air photo of the area, Figure 6.

22. Time of Impact /9

Because the impact was observed the time is given as 5 or 6 April 1965. The uncertainty is due to the fact that the observer cannot remember which of these days the observation was made.

The circumstances around the find are as follows. On one of the days in question the reporter of the find was occupied with woodcutting outside his home. Lively flying activity was in progress in the vicinity (jets). This in connection with the noise from the motor driven cross-cutter were the reasons why he did not make any observation himself. Another person was inside the house and heard on one occasion a bang which made the windows rattle. When the source of this bang was investigated, a round object was discovered in a small field, in 125 m from the house. The finder naturally connected the find with the flying activity that was in progress and contacted I 15. On April 7 a cheif warrant officer was sent with personnel from the regiment to the site to examine the found object and if necessary disarm it. When it was found that no piece of ammunition was involved, the find was taken charge of and transported to I 15.

Certain observations were made at the site. The point of impact was localized precisely. It was situated in a water-logged field at the western edge of Lilla Gronesjon (lake) ca 30 m from the waters edge. The impact produced a 1 dm deep depression. This corresponds to the thawed surface layer. Under it the ground was still frozen from the winter. The sphere lay ca 8.5 miles from the depression in compass direction 5800. The depression appeared to be fresh, without being filled with water in spite of the fact that the thawing was in progress.

23. Appearance

The shape is spherical, appearances practically identical with the Vemdals sphere. Melting damage present to about the same extent as in the previous find, on the other hand no damage from the impact, which according to the same calculations as that given in appendix 3 for the Vemdal sphere should have taken place at ca 75 m/s. One pole was practically undamaged and provided with a locknut and a nipple. It was therefore not difficult to measure these details. Figure 7 shows the sphere in the condition it was when found.

24. Dimensions /10

Weight	4.16 kg
Outside diameter	310.5 mm
Inside diameter	304.2 mm
Thickness of material (calculated)	3.15 mm
Volume (measured, 20°C)	15.0 dm^3

25. Material

Also here the preliminary examination showed that a titanium alloy was involved. No analyses have been made owing, among other things, to a desire to preserve the sphere intact.

26. Other

Visual examination was carried out as under 14 without results. The undamaged nipple was measured and compared with American standard threads (AN), the result as Figure 8.

27. Conclusions

With reference to what has been stated under 17, the conclusion is drawn that also the Boras sphere is derived from a space vehicle of American origin.

3. POSSIBLE ORIGIN

On the basis of, among other things, Goddard Space Flight Center Satellite Situation Report (NASA) and Royal Aircraft Establishment Table of Artificial Earth Satellites summarizing lists of satellite launchings and descents are published annually in the technical aviation and space press.

Taking into consideration the inclination conditions and descent or trajectory termination data a first crude sorting can be made from the lists of possible satellites. It is found that among the US satellites it is practically only Thor-Agena and Atlas-Agena that can come into question. Thor and Atlas respectively are the booster rocket and Agena is the maneuverable satellite. A further sifting gives TAT = Thrust Augmented Thor as the most probable version of the Thor rocket, next Atlas as carrier rocket and Agena D as satellite version.

The Agena D satellite is equipped with spherical pressure tanks for two functions, on the one hand filled with nitrogen or nitrogen-freon gas for position orientation control by means of jet nozzles, on the other hand filled with helium for pressure adjustment of the propellant tanks of the pump fed rocket engine in the final stage, that contains the Agena satellite. /11

Depending on the program of the mission one or more pressure tanks are present both for position control and for the rocket engine. The tanks can be of different sizes with the outside diameter varying from ca 310 to ca 500 mm according to what can be estimated through measurements on published pictures.

Based on information given in DGRR-Mitteilungen -66 about a helium tank of 26 dm^3 for the engine part and an Agena-D picture in Spaceflight Vol. 8, No. 3, 1966, it is highly probable that the Vemdal sphere is such a helium tank, and there is some probability that the Borås sphere can be a similar one, somewhat smaller. This is also supported by the fact that the nitrogen-freon tanks for position control as a rule are somewhat larger, ca 420 mm in diameter.

The most probable satellite launchings are reproduced in the following table.

Official designation	Name		Inclination	Launched	Down	
hr	rocket	satellite	angle °	date	date	fragment
1964-27A	TAT	Agena-D	80,0 (1)	04/6-64	18/6-64	
32A	-"-	-"-	85,0 2	19/6	16/8	
36A	Atlas	-"-	89,4 3	06/7	08/7	The Vemdal Sphere
37A	TAT	-"-	85,0 2	10/7	08/8	(<-- see below)
43A	TAT	-"-	80,0 1	05/8	31/8	
45A	Atlas	-"-	95,5 4	14/8	25/8	
1965-26A	TAT	Agena-D	96,1	25/3-65	04/4-65	The Borås Sphere

Concerning the Vemdal sphere the probability, based on observations at the site of the find, etc., appears primarily to suggest one of the listed launchings.

Concerning the Borås sphere the data speaks unequivocally for 1965-26A. The indicated date is the only one that can come into consideration as regards a US satellite, and 4 April according to the US list can correspond to 5 April in Sweden.

If we combine reported observations from the trajectory termination of /12 certain satellites we find that just about 1965-26A a number of observations over Europe have been reported. The inclination 96.1° implies that the trajectory goes over densely populated parts of Europe. Among 1964 satellites listed the inclination 80° implies that the trajectory with descent in Vemdalen passed over the North Sea and sparsely populated areas in Scandinavia, while other inclinations give trajectory terminations over more densely populated regions. Of course the descent trajectory can escape observation and one can therefore only accord the inclination some probability estimation. In the table the figures after the inclination angle indicate this degree of probability, which together with the other circumstances should put 43A in the first place.

All Agena-D objects may be some kind of spy satellites, employer Air Research and Development Command, USAF. No indication whatever of the nature of the mission or the useful load of the satellite has been found in the literature or satellite catalogs.

Figure 9 shows Agena-D with placement of tanks.

4. CONCLUDING REMARK

As appears from the text the material analysis has been made relatively extensive. It has been found that available resources in this respect are fully adequate. For identification of unknown objects the material investigation could in the future be limited considerably.

For the identification of space vehicles guided by found fragments it is of great importance that time indication for impact or other observations from the last phase of the trajectory be given as accurately as possible. It can also be important that fittings, nipples and the like in the case of tanks be left undisturbed so that remaining content, if any can be analyzed.

Choppy terrain with mixed birch and spruce

Boggy ground with spruce curtains

Mainly birch brushwood

Figure 1. Typical Terrain Pictures from the Area of the Find in Vemdalen.

/13

/14

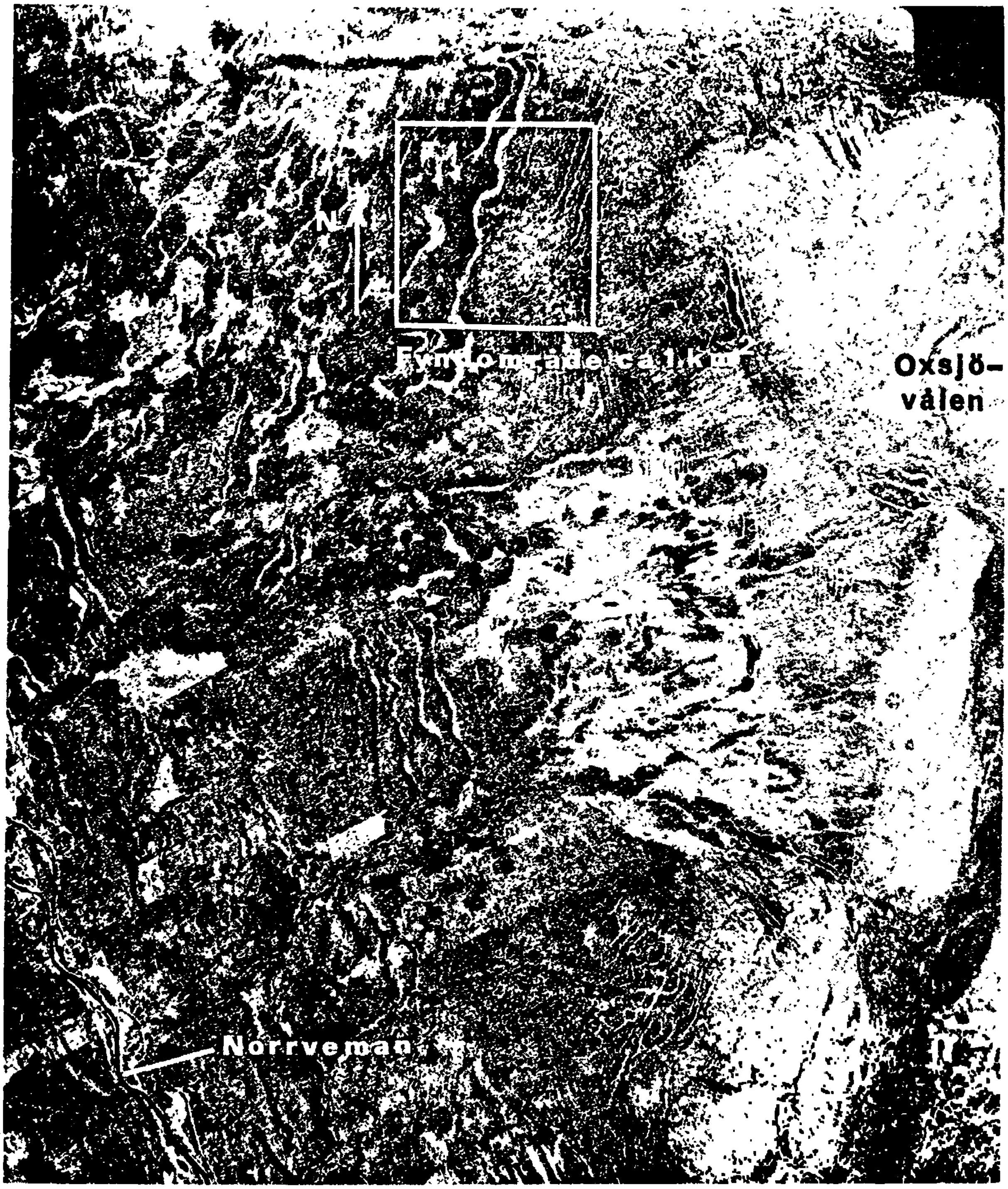

Figure 2. Area of Find in Vemdalen. Air photo: Rikets allmanna kartverk (Natural map Office) 1963. Approved for reproduction and distribution by Fikets allmanna kartverk. 17.4.1968

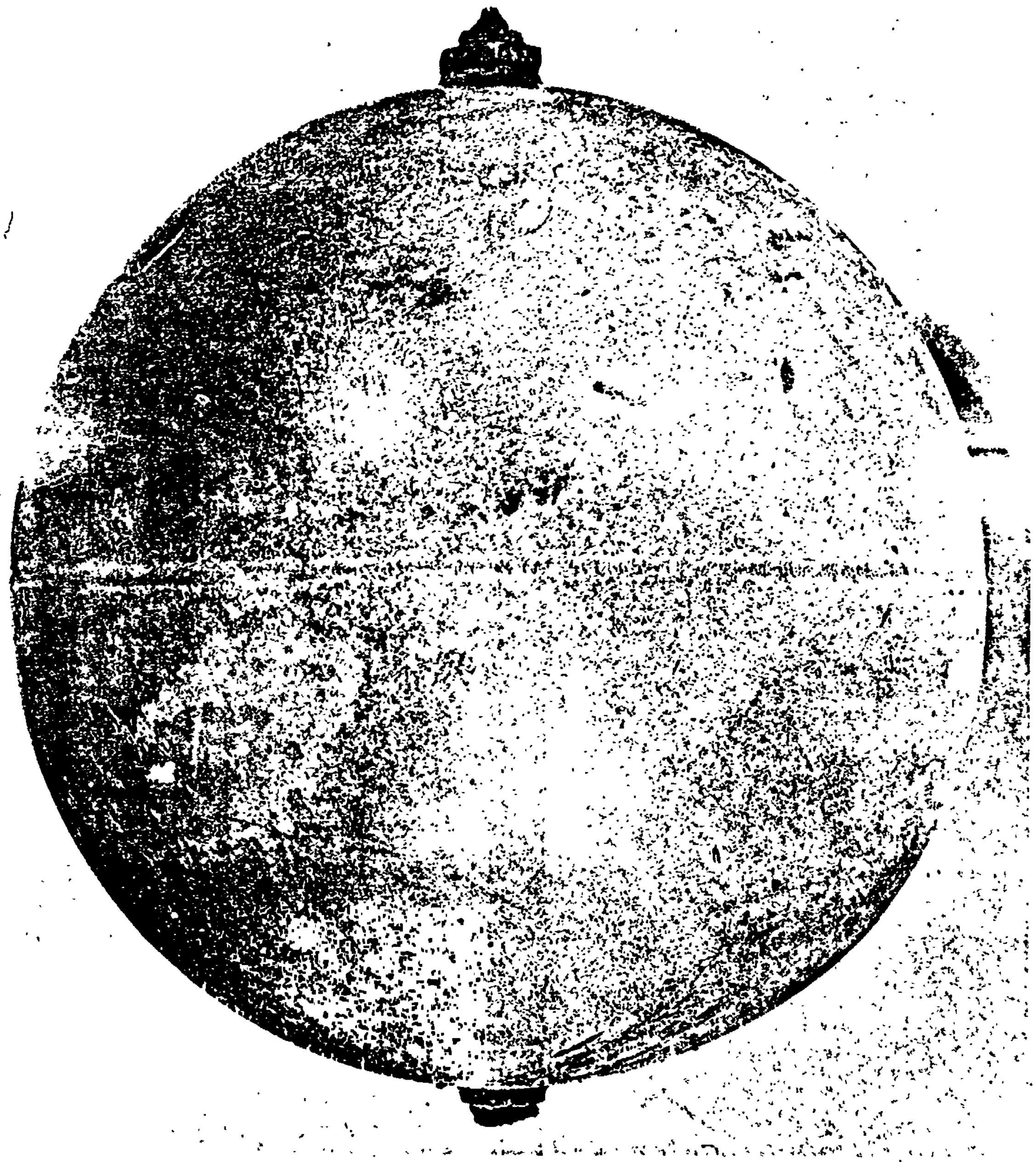

Figure 3. The Vemdal sphere in condition as found. The upper nipple is bond, the hole is clogged by molten metal. The lower nipple is solid the molten off part was probably threaded and used as point of attachment.

/16

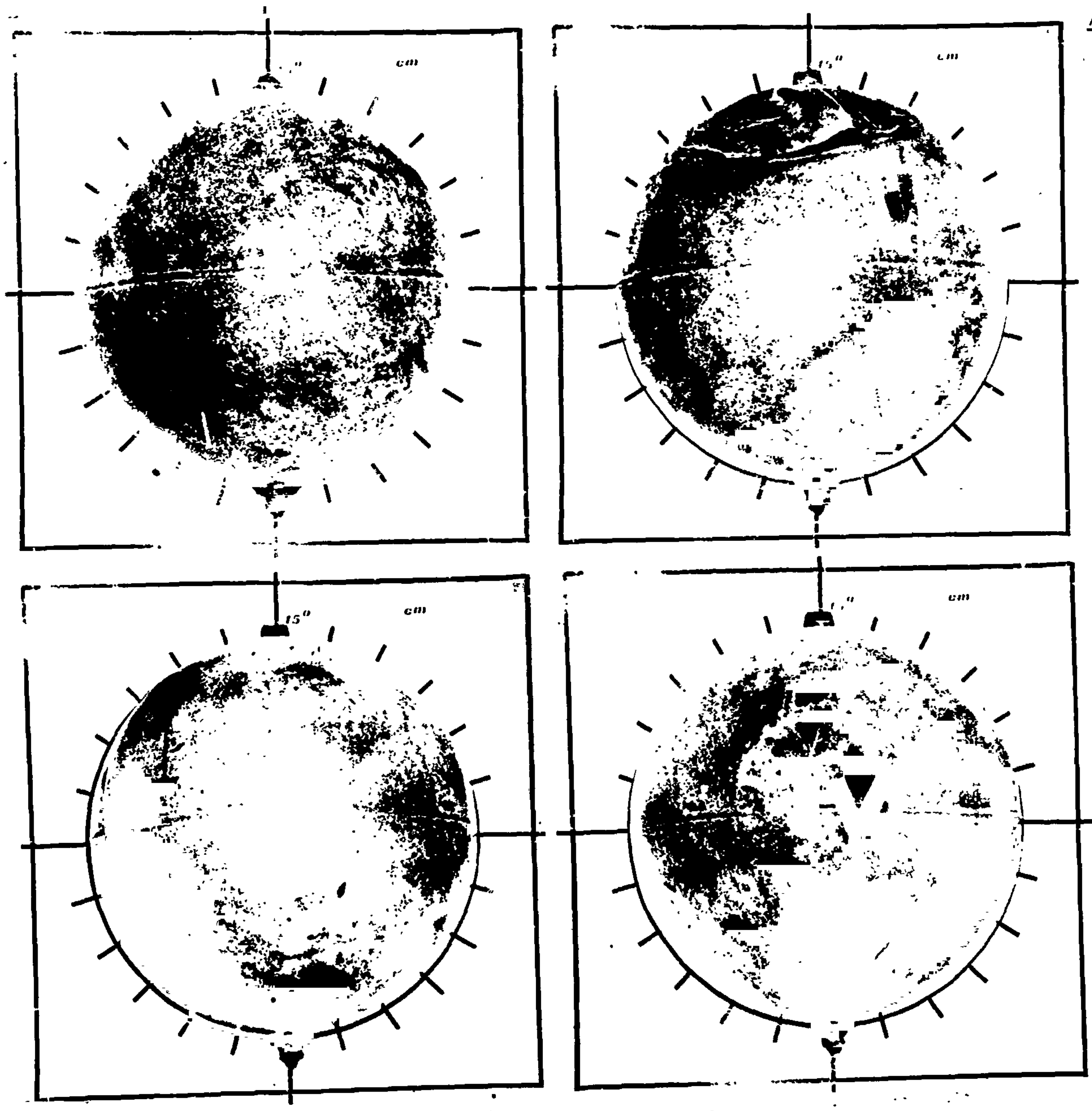

Figure 4. The Vemdal Sphere Seen from Four Directions, 90° between Each Picture.

/17

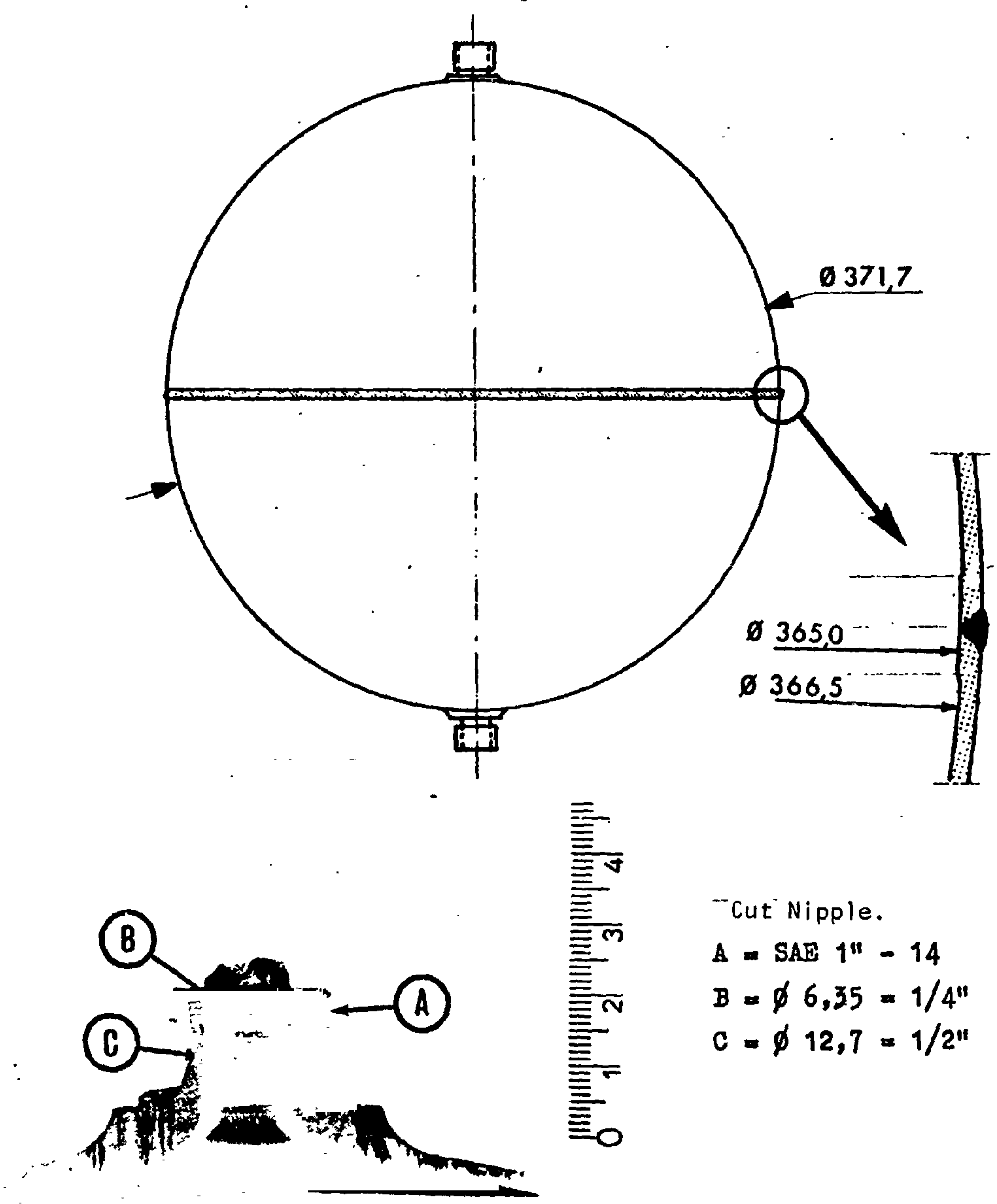

Figure 5. Dimension of Vemdal Sphere.

/18

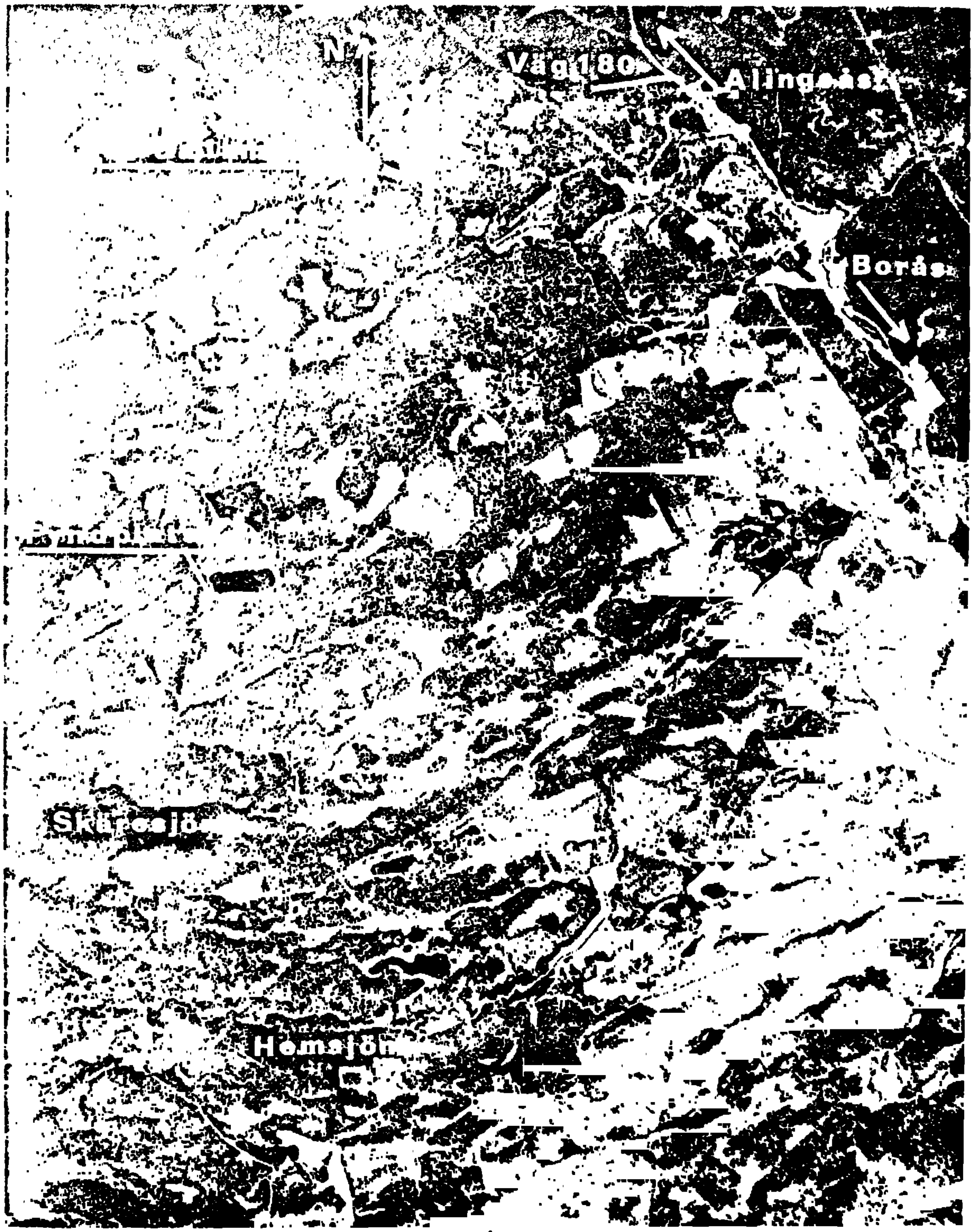

Figure 6. Site of Find in Borås Region. Air photo: Rikets allmanna kartverk (Natural map office) 1964. Approved for reproduction and distribution by Fikets allmanna kartverk. 17.4.1968

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Figure 7. Borås Sphere in Condition as Found.

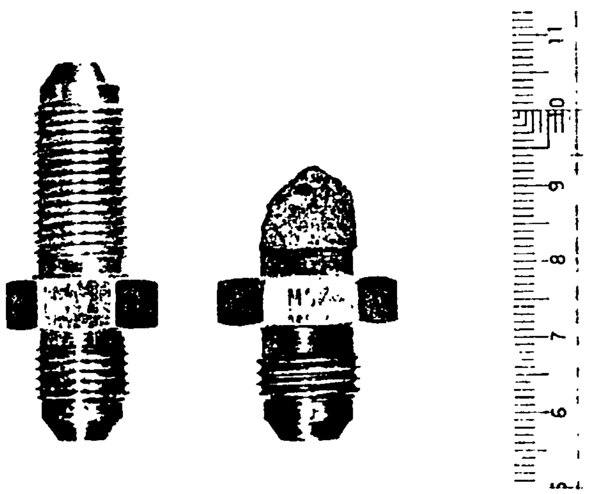


Figure 8. The Connecting Nipple
Compared with an AN Standard Nipple
Wrench width: 13/16"
Height of Hexagon: 15/64"
Thread: UNF 9/16" -8,60°
Cone Angle (whole): 72°

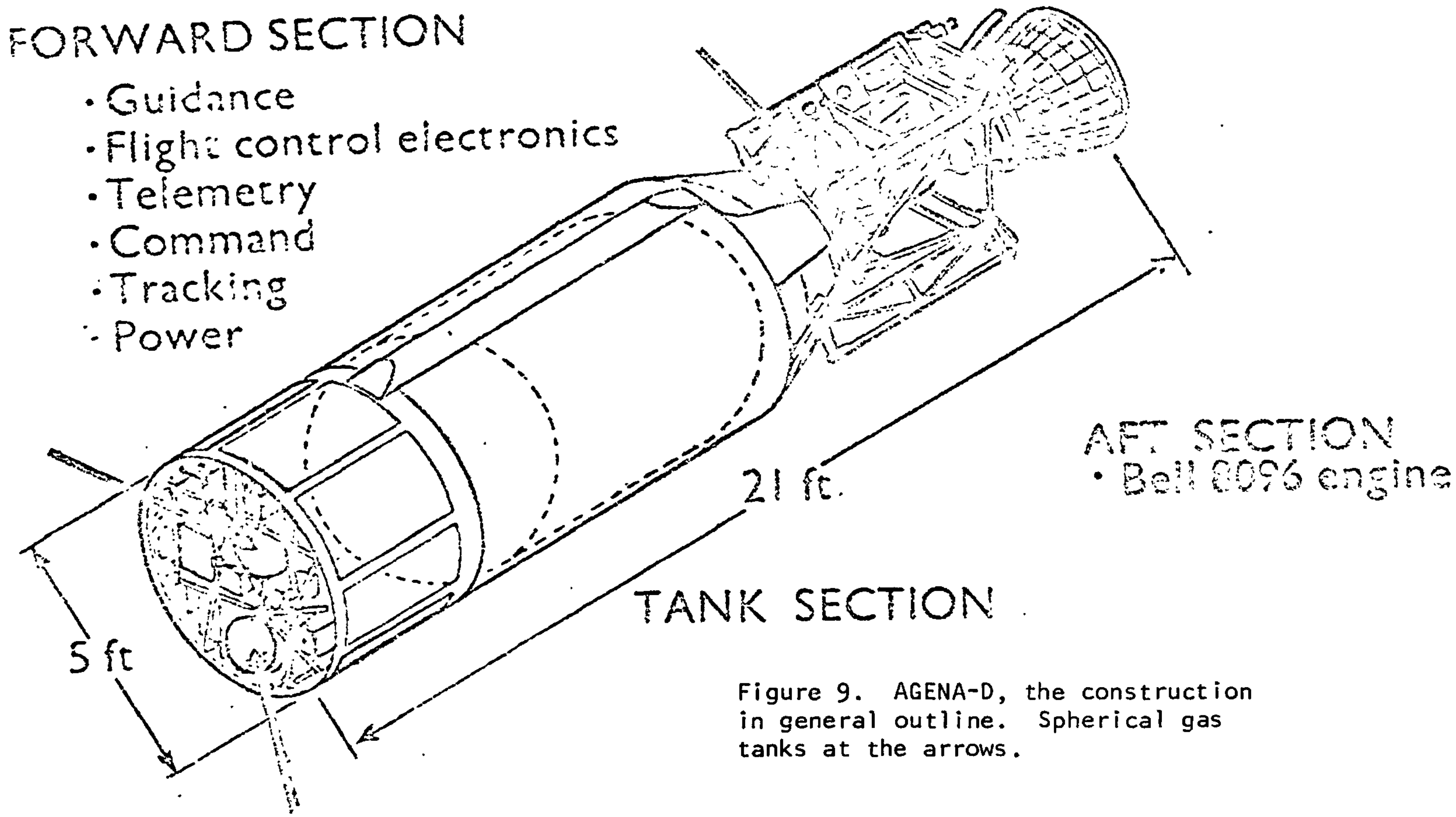


Figure 9. AGENA-D, the construction in general outline. Spherical gas tanks at the arrows.

/20

Appendix I /21

II Military Command
Military Command Staff
Ostersund

II mils (military dictrict) 4, 7 Oct 1964

Chief, Defense Staff Section II

Report concerning foreign material
Two enclosures
Fst/Und 6/12 1961 no. H 43:5:4 and 14/12 1962 no. H 8100-11

Concerning find in the form of spherical metal ball with ca 40 cm diameter, which was found in Harjedalen and about which articles have been inserted in among others Ostersunds Posten and Dagens Nyheter in the middle of October MB (the military command) has the honor to report as follows:

Finder:
Farmer Olov Gradin, Vemdalen (tel 152). Mr. Gradin came upon the find while moose hunting 7 - 9 Sept.

Measures taken:
Mr. Gradin delivered the find in turn to police offices Kvarneland, Vemdalen (tel 125) 11 Sept. On a visit to Ostersund 1 Oct. Kvarneland delivered the find to the military district security officer who arranged for a technical examination of the find at F4. Technical report of this examination is enclosed. The sphere was sent from F4 to FOA, Stockholm 80 on 8 October.

Site of find:
Ca 1.5 km N of Vemdalen church village between Nasvallen and Oxjoralen in forest, boggy ground. The sphere lay on top of the ground and may have fallen when the ground was snow covered.

Other:
Copy of letter from Sven Olsen, engineer, Box 627 Tuolluvaare is enclosed.

The finder has declared a desire to have the find returned to him in case it should be without interest for military or scientific institutions.

MB suggests that a reward of suitable size be paid to the finder in accordance with the above mentioned regulations.

By Authority of the Military Commander

Arne Rolff
Acting Chief of Staff

For information
FOA
Within the Staff, C Section -a

Copy

Technical report on unidentified find ca 15 km N of Vemdalen church village about 8 Sept. 1964.

The find, which was made available to F4 through II Milo, Ostursund, consists of a metal sphere welded together from two halves. The diameter of the sphere is ca 37.8 cm, the material appears to be steel plate, similar to MS 23, but not magnetic. The thickness is ca 2.8 mm (7/64" ?). The weld, which goes along a great circle, is very even, probably machine weld.

At the poles of both hemispheres there are nipples, probably originally connections. Both have melted. One is threaded and fitted with a hex nut with 1 1/2" width. The apex angle of the thread is 55°, diameter ca 24.6 mm.

The sphere has a dent produced by external force, ca 200 x 120 mm, with bursting of the plate (providing opportunity for thickness determination above). The sphere has no visually observable residue of contents and is not radioactive. The outside surface gives the impression of being oxidized, possibly tempered in the presence of air.

Froson 5 October 1964
H. Enderlein, Chief Flight Engineer

Conformity of photocopy with original certified
Ostursund 7 October 1964
E Wolger, K.b.

Memo Concerning Examination of Foreign Material
FOA Dnr 097-2136:1, 9 Oct. 1964

A first examination took place at L89 with, among others, Haglund, FOA 2, Moore, FOA 3 and the undersigned present. It was agreed that FOA 1 should co-ordinate possible continued investigation (Hjertstrand).

1. General

The object looks like a spherical high pressure gas tank. It has probably been exposed to heating over its entire surface, unevenly distributed. The connections are partly melted off. On one side denting and material failure have occurred. Identification is lacking unless some indication in one place can be amplified. The material is not magnetic. At the location of the breakage, probably due to impact on stone, the thickness of the material has been measured at two points--2.65 mm. With the diameter 372 mm and the weight measured at 5.28 kg, it is found that, provided the thickness of the material in the intersphere is that measured above, the spec. weight of the material is 4.5. Among structural material the only one having this value is titanium.

Provided further checking confirms that the material is titanium the find can be of interest, since titanium is a rather exclusive structural material, which only recently has become extensively used for modern jet planes and in space technology. If the object is derived from an airplane or a space vehicle and if its trajectory has become such that an aerodynamic position of equilibrium has come into existence for the passage through the air layer closest to the ground, the impact velocity with an assumed vertical or nearly vertical final phase prior to the impact can be calulated at ca 70 m/sec. The appearance of the damage,etc., in the find does not contradict such a course.

It is regarded as being of interest, not least for the working out of routine and method, to try to establish the origin, purpose and history of the object.

2. Preliminary Proposal for Investigation /24

Joint examination by FOA representatives for rocket technology, materials and materials analyses, shop technique and radiation measurement. Then decisions can be made on necessary interventions and sequence of operations, which tentatively include

- precise determination of dimensions
- searching for identification markings
- material in walls and connections
- exposure to temperature
- exposure to radiation
- corrosion and/or other study to estimate how long the object can have lain where found, possibly what it may have contained during operation
- data on thread, surface treatment, manufacturing method, etc.

Furthermore, the site of the find ought to be examined for investigation, among other things, of the direction of impact and whether additional finds can be made. Views to be obtained from the finder about how long the find may have remained undiscovered. (At the present he is engaged in forestry work and is away from home.)

3. Other

The finalizing of the investigation to be determined by the fairly probable results that are produced. In the case of space-technical origin a further encirclement can possibly be attempted by means of NASA and COSPAR tables and in cooperation with FOA 3, and also return to the country of origin may be considered. The cost of the investigation, especially in case it is extensive and outsiders must be called on, should be taken from special funds.

FOA 1, 16 Nov. 1964
Ake Hjertstrand

Conditions of Equilibrium for Falling Sphere

With equilibrium between weight and aerodynamic resistance,

$W = C_D \cdot X \cdot q$ where
W = weight of sphere kg
C_D = resistance coeff
X = cross section area m^2
q = dynamic pressure kg/m^2

C_D varies with Reynolds number.

We designate:

v = velocity of fall m/s
d = diameter of sphere m
ρ = air density $kg\ s^2/m^4$
ν = kinematic viscosity m^2/s
Re = Reynolds No. $= \frac{v\,d}{\nu}$

We get with inserted numerical values for the air layer next to the ground:

$Re = v \cdot 0{,}0257 \cdot 10^6$
$q = v^2 \cdot 0{,}0625$ kg/m^2
$X = 0{,}1088$ m^2
$W = 5{,}23$ kg

$v =$	25	50	75	100	m/s
$Re =$	0,64	1,29	1,93	$2{,}57 \cdot 10^6$	
$C_D \approx$	0,10	0,15	0,17	0,19	
$C_D \cdot X =$	0,011	0,016	0,018	0,021	

(According to NACA TN 312)

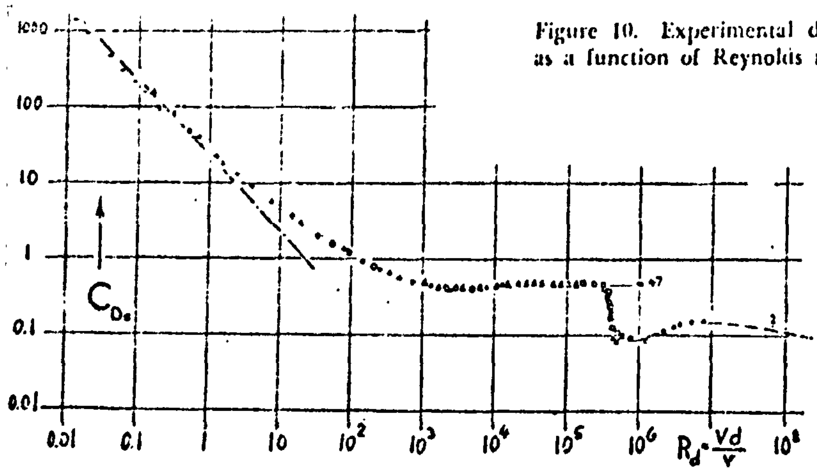


Figure 10. Experimental drag coefficients of the sphere as a function of Reynolds number.

Data from Fluid Dynamic Drag by
Dr S F Horner, 1958.
Library of Congress
Catalog Card 57-13009

Data used here from NACA TN 312

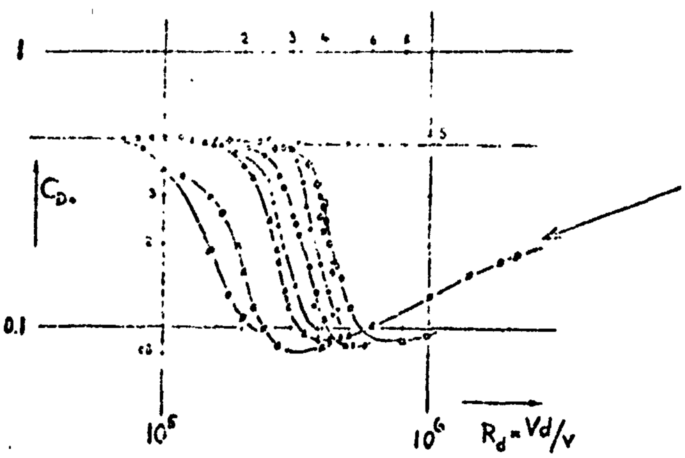


Figure 11. Presentation of typical experimental results on the drag coefficient of the sphere in the critical range of Reynolds number.

As is apparent actual C_D data with turbulent flow lie within the central Re range

From $W = C_D \cdot X \cdot q = C_D \cdot X \cdot 0{,}0625\ v^2$ we get

$$v = \sqrt{\frac{5{,}28}{0{,}0625(0{,}011 \text{ à } 0{,}021)}} \approx 88 \text{ à } 63 \text{ m/s}$$

With C_D =	0,15	$C_D \cdot X$ =	0,0163 we get	$v \approx$ 72 m/s
	0,16		0,0174	70
	0,17		0,0185	68

Figure 12—A NASA technician examines a titanium nitrogen purge tank, used in the X-15 for emergency jettisoning and purging of propellants.

FABRICATION

The titanium pressure vessel program was initiated in mid-1957, with original development efforts aimed at drawing plate into hemispheres. Bosses and trunions were welded to the hemispheres and the hemispheres were then joined together in the final configuration.

This program was met with mixed success, before ultimately giving way to use of forged hemispheres containing integrally forged bosses and trunions. The forging approach overcame readily the major problem inherent in the design of the original spheres—premature failure at boss and trunion welds caused by triaxiality introduced during pressure loading with consequent bending moments in the lower ductility welded areas.

Standard forging techniques are employed in production of parts—containing any bosses, trunions and nozzle ports required—used in pressure vessel construction. Proper selection of deformation schedule and maximum working temperature insures optimum metallurgical characteristics of the forgings. Reasonable care during the forging sequence will preclude low ductility parts and the erratic pressure test results that ensue from them. Metallographic and mechanical property testing of forged hemispheres should be judiciously monitored.

After forging, the usual procedure is to rough machine the part, leaving sufficient stock to assure removal of the surface contamination resulting from high temperature heat treatment. For the alpha-beta alloys, Ti-6Al-4V and Ti-7Al-4Mo, this heat treatment is a solution treatment in the range of 1650°F to 1750°F, followed by a water quench. After this operation, the hemisphere is then finish machined prior to welding.

Both fusion welding and pressure welding are employed in the manufacture of titanium pressure vessels. When fusion welding is used, standard titanium welding practices must be observed to protect the weld area from atmospheric contamination. In general, the MIG (metal inert gas) approach has been selected.

In selection of filler wire, fabricators have specified either commercially pure or wire of the same grade as the composition of the base metal being welded. Design of weld joints must compensate for any strength dilution caused by the "softer" commercially pure wire, and/or the fact that the weld joint, particularly a fusion welded joint, is annealed rather than heat treated. It is generally sounder practice to beef up the weld flange, even though a slight weight penalty is imposed, than to attempt to solution treat a coarse, dendritic weld structure.

After welding, the sphere is aged, at a temperature consistent with the metallurgical characteristics of the alloy (800°F to 1100°F). This process serves two functions: it is an aging cycle for the solution-treated material and a stress relief operation on the weld. However, when the beta grade (Ti-13V-11Cr-3Al) is used, welding is completed only after final heat treatment, and the welds are retained in the as-welded condition.

Pressure welding entails heating the sections to temperatures slightly below the beta transus and then forcing the sections together under pressure. Since a much finer grain size is inherent in a pressure weld (properties can be considered forged properties, rather than cast), the final assembly—both parent metal and weld—can be solution treated and aged.

In rough machining operations, surface finish can be maintained at better than 100 micro-inches and wall thickness controlled to plus or minus 0.005-inch. The reliability and quality of the machined surface is illustrated by the fact that all failures of vessels induced to date have been initiated on the outside of the vessel.

Figure 13—Cylindrical forgings of the beta titanium grade at receiving inspection. Sections will be machined and two welded together to provide completed air reservoir bottles, each 3½ pounds.

Further demonstrating the machinability of titanium is a proved ability of fabricators to finish machine bosses—where dimensional tolerances must be held to plus or minus 0.010-inch—after the parts have been solution treated and aged.

The internal volume of titanium pressure vessels now in service has been controlled to plus or minus one-half of one percent.

Success in production of titanium pressure vessels through a variety of approaches is best evidenced by a comment from JPL:

"Safety is as much a factor of good manufacturing practice as it is of inherent capability of the metal. Titanium vessels have both going for them."

Use of Sheetmetal. Despite the fact that most titanium pressure vessels now in service have been manufactured from forged sections, the use of plate or sheet is seen as an important area of growth when large, thin-wall vessels are built.

Titanium alloy plate and sheet can be drawn and spun on equipment used in working with steel. In general, drawing and spinning are performed hot (800°F to 1300°F). In drawing the die is directly heated and the punch is heated by radiation and conduction. Blanks are then heated until they are the same temperature as the die. /28

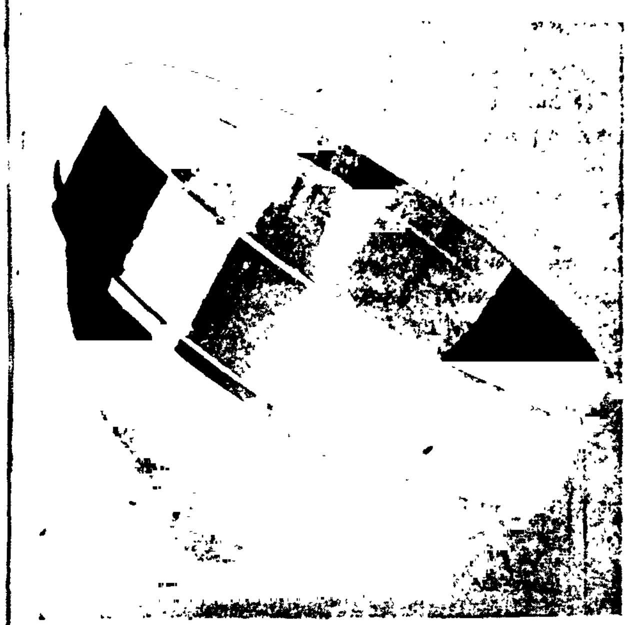


Figure 14—Ti-6Al-4V hemisphere, prior to pressure welding.

Use of coatings—such as TiForm—prevents the parts from picking up contaminants from the air during the operation.

The beta titanium alloy, however, can be drawn cold. Its availability in strip lengths and its good formability make it of interest to groups considering the need for on-site fabrication of large diameter parts.

However, certain problems arise here which must be considered: when large section size differences exist, i.e., nozzle ports, trunions, and girth weld flanges, the bending moments induced during pressure application may cause premature failures if these factors are not considered in design of the vessel.

PRICE

Because of its weight savings, titanium first went into service when its cost was six times that of steel on a volume basis, and titanium fabrication costs were quoted as "three times the costs of 4340."

The weight savings aspect has remained constant, while titanium prices and fabrication costs have steadily decreased.

The price table for titanium billet shown on the following page illustrates the downward trend in titanium raw materials cost.

In 1961 titanium billet was about twice the cost of nickel-bearing or PH steels on a volume basis. Even more significant is the fact that fabrication costs—which consume the lion's share of the parts dollar—are now 1:1 with these steels. Comments one fabricator:

"It takes the same amount of time in our shop to manufacture a part from Ti-6Al-4V titanium as from 17-7 PH or 4130 steel. Considering today's prices for

Table—Price of Ti-6Al-4V Billet

As of January 1	Price $ per lb.
1955	10.50
1956	9.10
1957	7.95
1958	7.10
1959	4.90
1960	3.75
Sept. 15, 1961	3.00

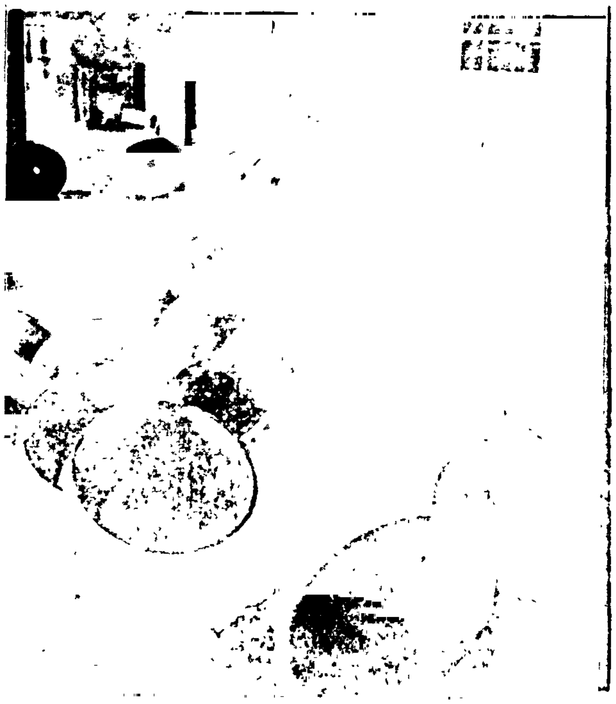
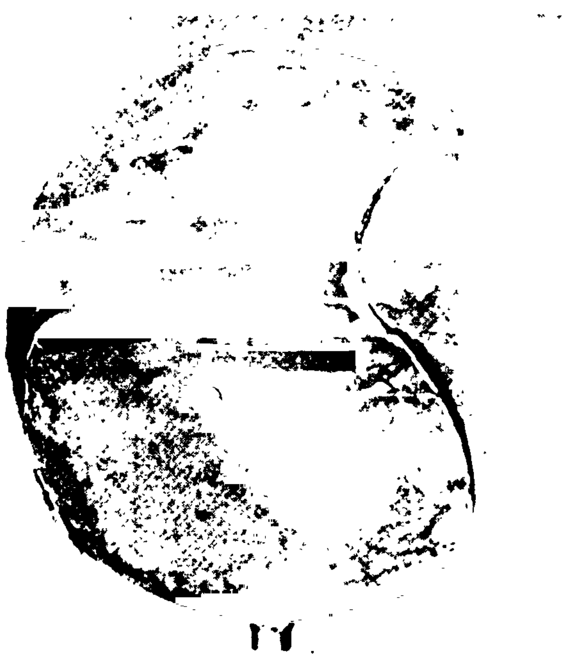


Figure 15—As-forged titanium hemispheres, approximately 24-inch diameter. Note completed pressure vessels in the background.



Figures 8 11– These vessels illustrate ductile characteristics of burst fractures in titanium pressure vessels. Note, cracks travelled across welds. The vessel, bottom left, was produced from Ti-13V-11Cr 3Al, all other vessels shown were manufactured from Ti-6Al 4V.

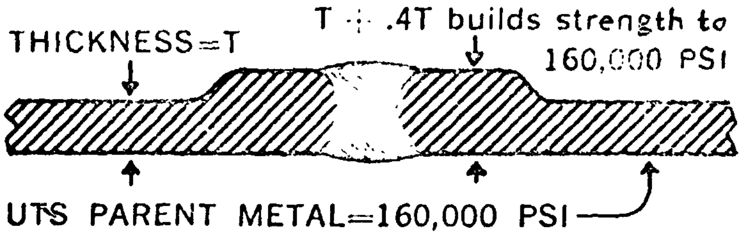
the input titanium, there seems little reason for not using titanium in airborne pressure vessels.

"A completed titanium pressure vessel now costs about twice that of a vessel manufactured from 4130, about 15 or 20 percent more than a unit produced from a PH steel."

And a completed titanium part weighs 40 percent less!

In brief, titanium means great product improvement at virtually no cost. Should you be considering materials for airborne pressure vessels, an investigation into titanium would well warrant your time and effort.

Above: Tank pressure tested to failure nole similarity of nipples to corresponding ones on found vessel.



Heat treated Ti-6Al-4V has weld efficiency of 60%. Commercially pure wire is generally used to build thickness to T + .4T to maintain strength of parent metal.

Structure of welded joint, compare Figure 5, page 13, and Figure 8, appendix 9.

NASA

Forsvarets Forskningsanstalt
Division 45

Routine order

(To be filled in by orderer, 2 copies to executing section)

Date of order 11 Oct. 1965

Executing section 454

Name of orderer: G. Larsson
Section 162
Order number

Desired date of completion

Definition of assignment:

Designation of sample: Part of pressure tank that was found in Norrland forest. Ti-alloy (5 Al + 2.5 Sn) or (6 Al + 4 V)

Spectrographic analysis to determine the type of composition and possible impurities

(To be filled in by executing section. Return 1 copy to orderer)

Date of arrival: 11 Oct. 1965
Date of assignment:

Result

Sample designation
Only the following have been determined in sample:

Al, V and Ti, no Sn

STATENS PROVNINGSANSTALT

STOCKHOLM

Certificate no. 5050,271

Orderer: Forsvarets Forskningsanstalt, Section 1, Sundbyberg

Object: 1 sample titanium

Received: 6 Oct. 1965

Examination: chemical analysis

Amount of sample: ca 4 g

Test result: Titanium, Ti 93.4%

Stockholm 12 November 1965
Statens Provningsanstalt
Section B
Gosta Perla

Heino Jurine

Forsvarets Forskningsanstalt
Division 45

Routine order

(To be filled in by orderer, 2 copies to executing section)

Date of Order:

Executing Section

Name of orderer: Gilbert Larsson

Desired date of completion:
As soon as possible

Section 162

Order number: 160400

Definition of assignment:

Designation of sample:

Sample taken from gas tank of Ti-alloy
Occurrence of Ti, Al, V, Sn, Mo, Mn, other?

Deliver sample of plate

(To be filled in by executing section. Return 1 copy to orderer)

Result
Sample designation

Date of arrival
Date of assignment

Spectrographic analysis:

The following elements have teen determined:

Relatively large amounts of Ti, Al, V and Mn.
Small amounts of Si, Mg and Fe
In addition there are traces of molybdenum, not entirely certain.

Comment:

All the elements indicated above with the exception of molybdenum can be regarded as determined with certainty. Ti, Al, V and Mn probably constitute alloy elements, while Si and Mg need not be any essential part of the alloy. The same is true of Fe, which possible can be derived from the preparation of the sample (sawing).

The sample was after some cleaning up, clamped directly in an electrode stand and spectra was exacted by means of high voltage, so called Feussner Spark.

STATENS PROVNINGSANSTALT

Certificate no. 5050,217B

STOCKHOLM

Orderer: Forsvarets Forskningsanstalt, Section 1, Sundbyberg

Object: 1 sample titanium

Received: 6 October 1965

Examination: Chemical analysis

Amount of sample: ca 4 g

Test result:

Aluminum, Al 6.2%
The sample examined corresponds to ASTM B
265-58 T, grade 5; 6 Al 4V.

Stockholm 21 February 1966
Statens Provningsanstalt
Section B
Gosta Perla

Heino Jurine

Metallographic Structure Investigation of a Welded Spherical Tank of Light Metal Plate

Performed by N. E. Karlsson, 1st Enjineer. FOA M

On request from FOA 1 a metallographic investigation has been carried out at FOA M of a spherical tank that was found in overgrown boggy, woodland in Vemdalen, Harjedalen. The tank, which has a diameter of ca 40 cm, consists of two hemispherically shaped parts which have been joined together by a very fine weld. The thickness of the plate is ca 3 mm. The halves of the tank are provided at each pole with a nipple. One nipple is threaded.

A big dent and cracking of the plate could be observed on one half, which indicated that the tank had fallen at high speed and had hit a hard base.

The outer surface of the tank, especially in an area close by the threaded nipple, is strongly discolored (oxidized) with numerous dark spots everywhere. On the threaded nipple several porosities are observed, similar to those that occur when a metallic material is heated to incipient melting. Prior to the fall of the spherical tank to the ground, the material has been subjected to intensive heating and the structure in the outer zone of the plate has changed markedly.

1. Purpose of the Investigation

At a preliminary examination carried out by FOA 1, it was found that the tank had been made of a light metal with a density which agreed well with the density of titanium metal (4.5 g/cm^3).

Several discriptions have appeared in the literature of similar type. The material used was titanium or some alloy with titanium base, and the tanks were provided as pressure vessels for compressed gases. These vessels are used aboard satellites and robots. The partly surface affected tank found in Vemdalen is probably of such origin.

The purpose of the metallographic investigation was to try to identify the metallographic structure of the material of the tank, whereby also, the possibility presented itself of being able to judge the nature of the influence the material had been exposed to.

Chemical, spectrographic and micro-x ray analysis of sample material also presented the opportunity for delivering qualitatively and quantitatively the components of which the material consists. /35

2. Execution of the Investigation, Preparation of Sample

Around the threaded nipple of the tank a circular disk was cut out (ca 10 cm in diameter) which was divided in two through the middle. This cross section through the nipple and its nearest surroundings is shown in Figure 1 below.

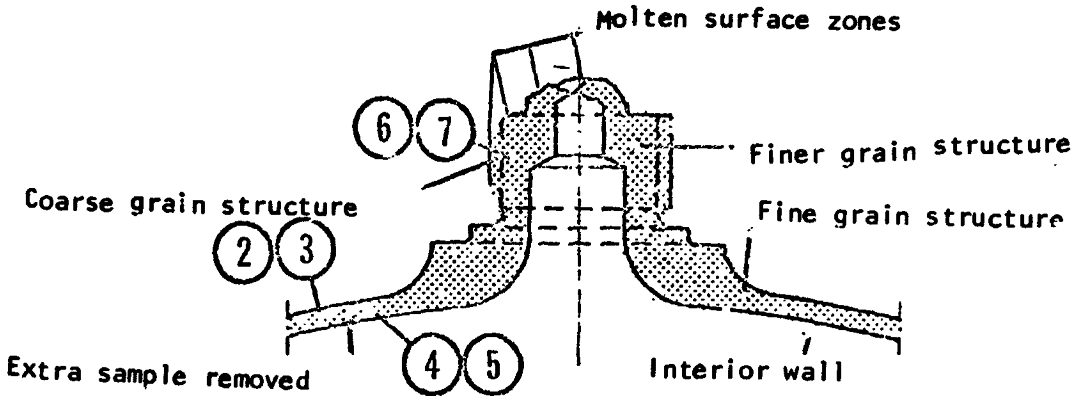


Figure 1. Cross Section in Natural Size Through the Sample. The Numbers refer to figure numbers.

From the cut-out sample a small piece was removed (as shown in Figure 1) from the wall of the tank and was embedded in bakelite. Also across the fine weld joint a sample was cut out, to make possible a closer examination of the structure of the weld.

The larger sample, through the nipple as well as the two other samples, was ground on water sprayed silicon carbide disks and thereupon polished with diamond paste and slurried Al_2O_3 powder (alumina), whereby a very bright shiny metal surface appeared. During the grinding and polishing it was observed that the sample material, in spite of continuous spraying with water or liquids for polishing, became quite hot due to a poor heat conducting quality, which among other things, suggests that the material of the tank can be titanium.

3. The Microstructure of the Plate Tank /36

In Figure 2 (40x) is shown the etched metallographic ground section through the wall of the tank near the threaded nipple. In this low magnification the individual grains come out very clearly. Within each grain a Widmannstatten structure is seen, that is characterized by lamella-like disks cross each other within the grains. This structure, which develops in certain metallic material through relatively rapid cooling from high temperatures resembles the structure of metionic iron. In the "old" grain boundaries a network of low temperature phase has been separated out during the rapid cooling, and from this grain boundary phase the interior of the grains is filled with lamellae of the same phase, which grow into the grains.

Figure 2. 40 x Metallographically Ground Section Through the Wall of the Plate Tank. The Sample was Etched in Saturated Oxalic Acid Solution Containing 2% HF.

The structure is otherwise characteristic of and identical with a two phase so-called alpha-beta titanium alloy of the type Ti/6 Al/4V that has been cooled rapidly from high temperature within the beta range. An example of such a structure can, for example, be found in Rare Metals Handbook.

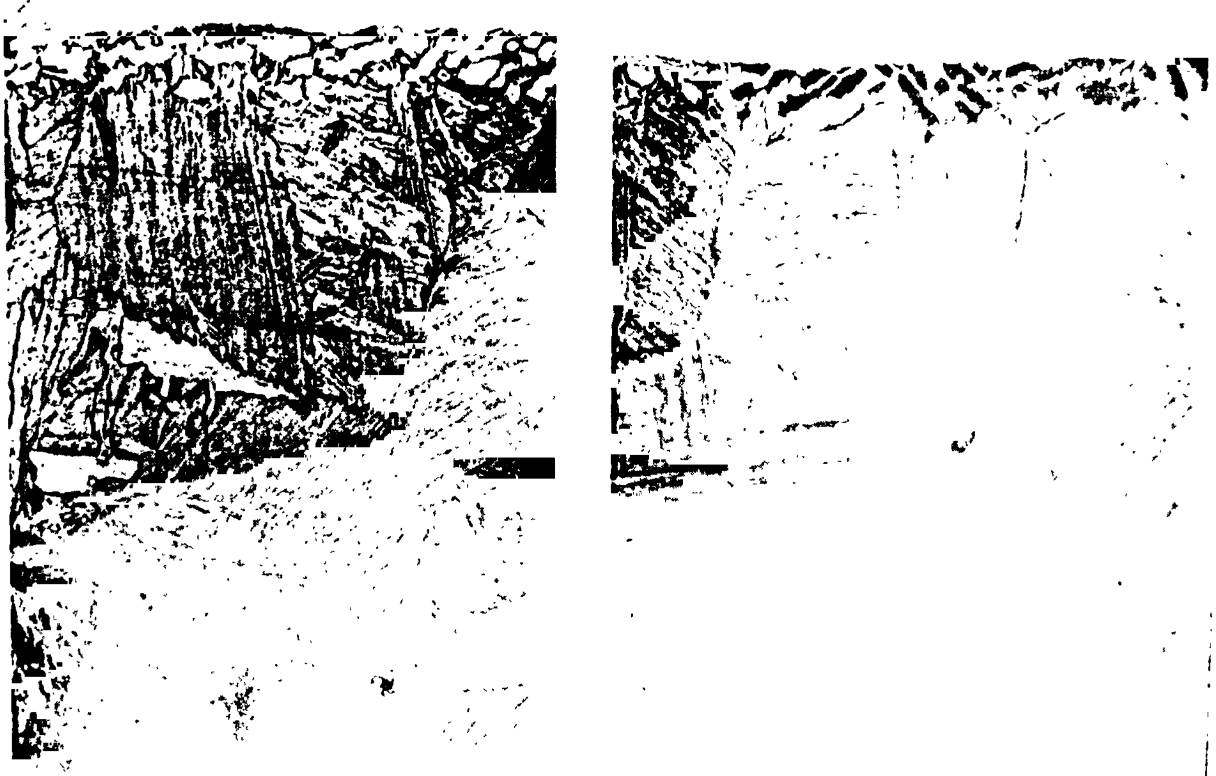
The structure appearing in the tank thus suggests that the material can be a titanium alloy of the alpha-beta type and that the structure was formed after the tank had been allowed to cool rapidly subsequent to intensive heating.

Figure 3 shows in higher magnification (400x) the microstructure in the interior of the plate wall in the same sample. /37

In the outer surface zone of the plate a markedly changed structure is observed. See Figures 4 and 5 (400x). A bright metallic phase appears in the thin surface zone, which might be due to the fact that the heating during a certain period has been so intensive that some element of the alloy has been rapidly vaporized--a phenomenon that resembles the pulling off of zinc in the surface layer of brass that is exposed to intensive heating or the cooling of steel closest to the oxide layer when heating in oxidizing atmosphere to high temperature.

This destruction of the surface zone of the plate tank thus constitutes a further indication that the tank has been heated intensively.

Figure 3. The Microstructure in the interior of the wall cross section of the tank. The sample taken from the plate close to the threaded nipple.



/38

Figures 4 and 5. 400x The Microstructure in the outer surface zone of the plate close to the threaded nipple.

4. The Structure in the Threaded Nipple:

By visual inspection of the etched structure in the nipple it was determined, among other things, that the grain size in the material close to the threads is considerably coarser (Figure 1) than in the plate material close to the nipple, which indicates that the thicker material there has been heated for a longer period to a high temperature.

The phenomenon that the surface of the threads showed typical formation of melting porosities also suggests that the temperature has been very high. The microstructure from these portions, Figures 6 and 7 (400x) to a certain extent resembles the structure of superheated ("burnt") steel, in which a partial melting down has taken place in the grain boundaries. The structure especially as regards Figure 7 could be composed to a solidification structure.

The picture material provides clear evidence that the material in the surface zone of the nipple has been subjected to a very intensive heating. /39

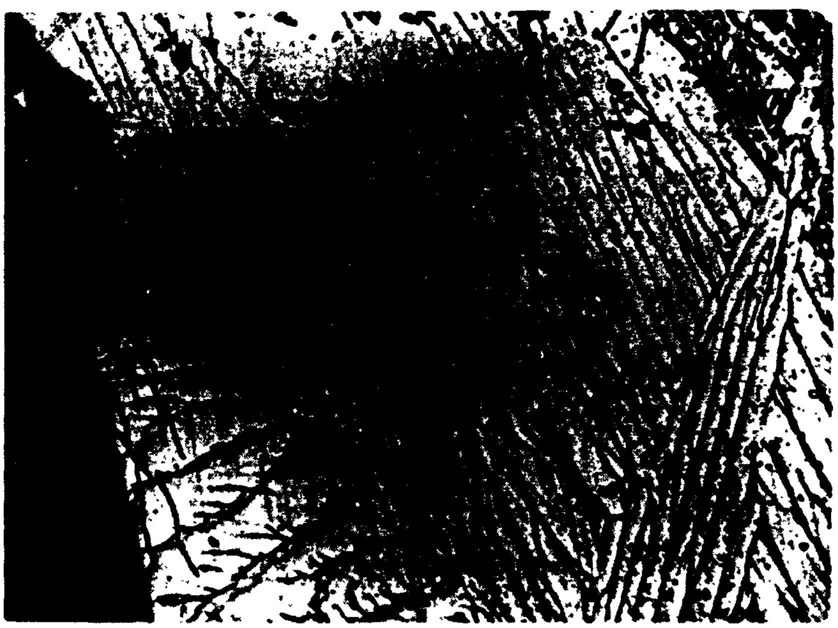


Figure 6. 400x. Microstructure in the Threads of the Nipple.

NASA

Figure 7. 400x. Microstructure in the Threads of the Nipple.

5. Metallographic Examination of the Welded Joint on the Tank /40

A grinding of a section of a sample taken across the weld on the tank has also been made, and the cross section surface was etched with the same etching agents. In the heat affected zones nearest to the weld itself the grain size is considerably larger than in the plate of the joined halves at a greater distance from the weld.

Figure 8 shows in ca 20x magnification the etching structure. No extra heat treatment appears to have been carried out to normalize the weld structure.

What is especially noted by visual inspection of the weld is its narrow width. It would not be unreasonable to assume that the two halves were electron beam welded, judging from the very near weld.

6. Microprobe Analysis of the Microstructure of the Plate Tank

At Svenska Silikatforskningsinstitutet (Swedish Institute for Silicate Research), Gothenburg Claes Helgesson, licentrate in Technology, FOA M, has carried a microprobe analysis (live scanning and surface scanning) of the plate sample that was cut out close to the threaded nipple. Scanning pictures of the distribution of Mn, Al and V (K_α-radiation) and diagram showing contents of Al, V, Mn and Ti have been recorded.

Judging from figures and diagrams from surface and live scanning respectively, no pronounced accumulation of alloy elements is found in the grain boundaries, which should indicate that the alloy is monophase. With regard to the fact that the examined structure was formed during rapid cooling the complete diffusion and separateness has, however, been effectively repressed, and this might be the reason for the result obtained. To be able to determine with certainty whether the structure is mono or polyphase a sample should have been subjected to solution treatment at a temperature of ca 1000°C, when the alloy is monophase and consists of the so called beta phase, and have been permitted to cool slowly. Thereby possible separated grain boundary phases could have been determined microscopically with a high degree of certainty and dissolving contents of included alloy elements in these phases could be recorded by the miscroprobe analysis.

7. Result /42

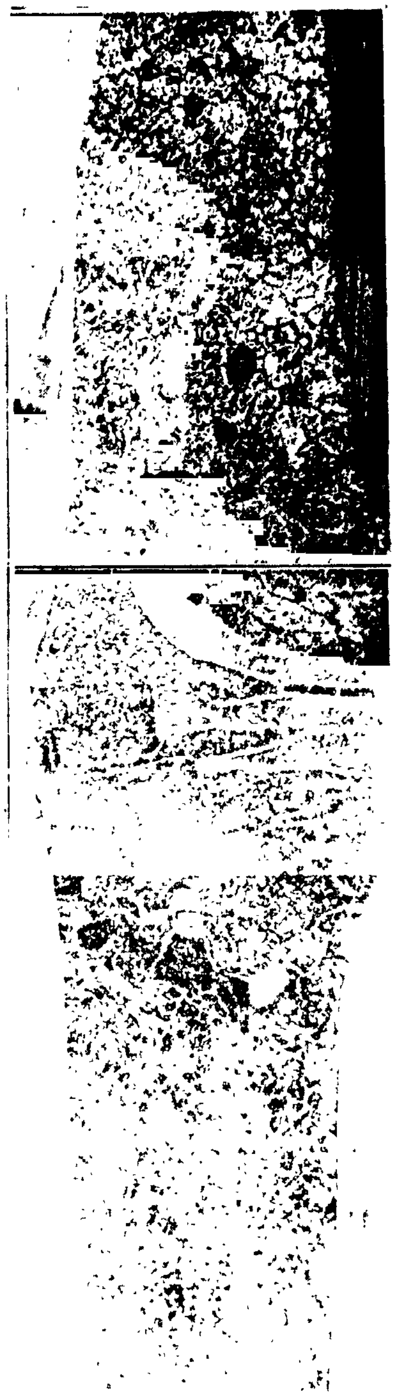
Linear microprobe analysis (like separately performed quantitative chemical and spectroscopic analysis) of the material of the tank has produced the result that the composition could be determined.

Al	ca 7%
V	ca 5%
Mn	ca 0.1 - 0.25%
Ti	the rest

With that there should not be any doubt that the alloy is of the well known type Ti/6Al/4V.

In West European literature it has been mentioned that this alloy has been used to a large extent as material in pressure vessels for compressed gases. This alloy is also used to a large extent in the USSR.

In the US the alloy is standardized under the designation ASTM B 265-58T. It belongs to the so-called α-β alloys of titanium alloys and is thus biphase. It can be hardened by aging, whereby the alloy is solution treated at 760 - 980°C, quenched to room temperature and heat aged at temperatures in the range 430 - 600°C. As in most other α-β alloys with titanium base the quick quenching from the beta condition results in a meta-stable β phase being retained in the structure, which later, by the heat aging produces α phase formations in a base mass of β phase. A fine structure is obtained,which is considerably stronger than an annealed structure. As a general rule it is true, that the thinner the section is, the greater hardening effect will be produced by the complete heat treatment (solution treatment, quenching and heat aging).



Inside Wall

Outside Wall

Figure 8. Metallographic Polished Section Through the Weld in the Spherical Titanium Tank. The Section Surface Has Been Etched 5 sec. in a Saturated Oxalic Acid Solution Containing 2% HF.

Appendix 10 /43

Royal Gota Air Wing

9 June 1965

For 2. Flight Squadron

Report on Found Foreign Object

A presently unidentified object has been transmitted from I 15, Borås, through the agency of Quavtermartes Fredriksson, to F 9. This object is reported to have been found in connection with flying activity over a farm immediately north of Borås by the owner of the farm, probably 5 or 6 April, 65, or in any case one day during the week 5 April - 10 April.

The found object appears to be a pressure tank of spherical shape with a diameter of 310 mm, welded together of two hemispheres. The material is unmagnetic as is a screw coupling provided with SAE threads. The tank has been exposed to so high temperature that a melting down has taken place on the one hand in the coupling and on the other hand in the tank wall at a point that is the antipode of the coupling. There are no impact damages in the form of deformation, possibly because the object is said to have fallen in a bog.

No further details have been discovered at the place of impact.

Request directive about how further investigation is to be carried out by F 9.

2 photos enclosed
By order of Chief F 9
Y. Hallbrink
Technical Chief

Chief of
Report on Found Object

The chief of F 2 has the honor
concerning found object.
Further investigation to be made by
The object has been transmitted to FOA
through CF 9.

By order of Chief of Squadron
Sten Hedstron
Deputy Chief of Squadron

S. Henrickson

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